MARKED-UP VERSION OF

ENGLISH TRANSLATION OF

INTERNATIONAL APPLICATION

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~~DESCRIPTION~~

SURFACE ACOUSTIC WAVE DEVICE

BACKGROUND OF THE INVENTION

1. ~~Technical~~ Field of the Invention

[0001] The present invention relates to surface acoustic wave (SAW) devices used for resonators or band-pass filters and a method for manufacturing the same. More specifically, the present invention relates to a SAW device including an ~~having a structure in which an~~ insulating layer that covers an interdigital transducer (IDT) electrode.

2. Description of the Related Art

~~Background Art~~

[0002] In duplexers (DPX) or radio frequency (RF) filters used in ~~a~~ mobile communication systems, a wideband characteristic and a favorable temperature characteristic must ~~are required to~~ be satisfied at the same time. SAW devices that have conventionally been used for DPXs or RF filters use a piezoelectric substrate made of 36° to 50°-rotated Y-cut X-propagating $LiTaO_3$. This piezoelectric substrate has a temperature coefficient of frequency of about -40 ppm/°C to about -30 ppm/°C. As a method for improving the temperature characteristic, a method for forming a SiO_2 film having a

positive temperature coefficient of frequency to cover an IDT electrode on a piezoelectric substrate is~~has been~~ known. Fig. 30 shows an example of a method for manufacturing this type of SAW device.

[0003] ~~——~~As shown in Fig. 30A~~(a)~~, a resist pattern 52 is formed on a piezoelectric substrate 51 except in a region where an IDT electrode is to be formed. Then, as shown in Fig. 30B~~(b)~~, an electrode film 53 defining ~~to serve as~~ an IDT electrode is formed over an entire surface. Then, the resist pattern 52 and the metal film on the resist pattern 52 are removed ~~by~~ using a resist removing agent. In this manner~~way~~, an IDT electrode 53A is formed, as shown in Fig. 30C.~~(c).~~ Then, as shown in Fig. 30D~~(d)~~, a SiO_2 film 54 is formed to cover the IDT electrode 53A.

[0004] Japanese Unexamined~~ The following~~ Patent Application Publication No. 11-186866 (Patent Document 1) discloses a method for manufacturing a SAW device including an insulating or semiconducting protective film covering ~~to cover~~ an IDT electrode of the SAW device, the method is used for reasons~~having a purpose~~ other than improving the above-described temperature coefficient of frequency. Fig. 31 is a schematic cross-sectional view showing the SAW device described in this known art. In the SAW device 61, an IDT electrode 64 ~~63~~ made of Al or an alloy primarily including ~~mainly containing~~ Al is disposed~~lies~~ on a piezoelectric substrate 62. An insulating or semiconducting inter-electrode-finger film 64 is disposed~~lies~~ in a region except the region where the IDT electrode 63 is disposed.

[0005] ~~lies.~~ Furthermore, an insulating or semiconducting protective film 65 is arranged~~lies~~ to cover the IDT electrode 63 and the inter-electrode-finger film 64. In the SAW device 61 described in this known art, the inter-electrode-finger film 64 and the protective film 65 are made of an insulating material, such as SiO_2, or a semiconducting material, such as silicon. According to this known art, forming the inter-electrode-finger film 63 suppresses degradation of a characteristic caused by inter-electrode-finger discharge due to a pyroelectric~~pyroelectire~~ property of the piezoelectric substrate 61.

[0006] On the other hand, Japanese Unexamined~~the following~~ Patent Application Publication No. 61-136312 (Patent Document 2) discloses a one-port SAW resonator. This one-port SAW resonator is manufactured by forming an electrode made of metal, such as aluminum or gold, on a piezoelectric substrate made of quartz or lithium niobate, forming a SiO_2 film thereon, and then ~~by~~ smoothing the SiO_2 film. According to ~~this~~ Patent Document 2, a favorable resonance characteristic is ~~can be~~ obtained by smoothing.

~~Patent Document 1: Japanese Unexamined Patent Application Publication No. 11-186866~~

~~Patent Document 2: Japanese Unexamined Patent Application Publication No. 61-136312~~

~~Disclosure of Invention~~

[0007] As shown in Figs. 30A-30D~~. 30~~, in the known method for manufacturing a SAW device of forming a SiO_2 film, in order to improve a temperature coefficient of frequency, the height of the SiO_2 film 54 differs at a portion where the IDT electrode 53A exists and at a portion where the IDT electrode 53A does not exist. Such an uneven surface of the SiO_2 film 54 disadvantageously increases insertion loss. This unevenness becomes more significant as the thickness of the IDT electrode increases.~~becomes thicker.~~ Therefore, the film thickness of the IDT electrode cannot be increased.

[0008] In the SAW device described in Patent Document 1, the inter-electrode-finger film 64 is formed between electrode fingers of the IDT electrode 63 and then the protective film 65 is formed thereon. In this method, the surface of the protective film 65 can be smoothed.

[0009] However, in the structure described in Patent Document 1, the IDT electrode 63 is made of Al or an alloy primarily including~~mainly containing~~ Al. The inter-electrode-finger film 64 contacts the IDT electrode 63, however, ~~but~~ a sufficient reflection coefficient cannot be obtained in the IDT electrode 63. Accordingly, ripples ~~ripple is easy to~~ occur in a resonance characteristic, for example.

[0010] In the manufacturing method described in Patent Document 1, a resist formed on the inter-electrode-finger film 64 must be removed ~~by~~ using a resist removing agent before forming the protective film 65. At this time, however, the IDT electrode

63 may be corroded by the resist removing agent. For this reason, a metal that is susceptible to corrosion cannot be used as a material of the IDT electrode. In other words, the type of metallic material of the IDT electrode is limited.

[0011] On the other hand, in the one-port SAW resonator described in Patent Document 2, a specific preferred embodiment includes only an example in which an electrode made of Al is formed on a quartz substrate, although it is described that quartz or lithium niobate is used for the piezoelectric substrate and that the electrode is made of aluminum or gold. That is, ~~this~~ Patent Document 2 does not refer to a SAW device using another substrate material or another metallic material.

SUMMARY OF THE INVENTION

[0012] To overcome the problems described above, preferred embodiments ~~An object~~ of the present invention ~~is based on the above-described circumstances of the known arts and is to~~ provide a SAW device in which an insulating layer is disposed~~lies~~ between electrode fingers of an IDT electrode and on the IDT electrode, and a method for manufacturing the same. More specifically, preferred embodiments~~an object~~ of the present invention ~~is to~~ provide a SAW device having a greatly improved ~~favorable~~ resonance and filter characteristics, in which the reflection coefficient of an IDT electrode is sufficiently high and degradation of characteristic due to ripples in the resonance

characteristic are~~can be~~ suppressed, and a method for manufacturing the same.

[0013] The ~~Another object of the present invention is to provide a~~ SAW device according to preferred embodiments of the present invention not only has~~having~~ a favorable characteristic with a sufficiently high reflection coefficient of an IDT electrode, but also has~~having~~ a high degree of freedom in selecting a metallic material of the IDT electrode and is ~~being~~ capable of suppressing an adverse effect of corrosion of the IDT electrode~~, and a method for manufacturing the same~~.

[0014] In addition, the ~~Another object of the present invention is to provide a~~ SAW device according to preferred embodiments of the present invention not only has~~having~~ a favorable characteristic with a sufficiently high reflection coefficient of an IDT electrode and is ~~being~~ capable of suppressing degradation of characteristic due to corrosion of the IDT electrode, but also has~~having~~ a favorable temperature coefficient of frequency~~, and a method for manufacturing the same~~.

[0015] According to a first preferred embodiment,~~invention, there is provided~~ a surface acoustic wave device includes ~~including~~ a piezoelectric substrate made of $LiNbO_3$ having an electromechanical coupling coefficient whose square (k^2) is at least about 0.025,~~ or more;~~ at least one electrode ~~that is~~ made of a metal having a~~whose~~ density ~~is higher than that of Al or an alloy mainly containing the metal or~~ that is ~~higher than that~~composed of Al or an alloy primarily including

the metal or that includes laminated films made of a metal whose density is higher than that of Al or an alloy primarily including~~mainly containing~~ the metal and another metal, the electrode disposed~~lying~~ on the piezoelectric substrate,~~;~~ a first insulating layer disposed~~lying~~ in a region other than a region where the at least one electrode is disposed~~lies~~, the thickness of the first insulating layer being substantially~~almost~~ equal to that of the electrode,~~;~~ and a second insulating layer covering the electrode and the first insulating layer. The density of the electrode is at least about ~~more than~~ 1.5 times greater~~higher~~ than that of the first insulating layer.

[0016] ~~—~~According to a second preferred embodiment,~~invention, there is provided~~ a surface acoustic wave device includes ~~including~~ a piezoelectric substrate made of $LiNbO_3$,~~;~~ at least one electrode disposed~~lying~~ on the piezoelectric substrate,~~;~~ a protective metal film made of a metal or an alloy that is more corrosion-resistant than a metal or alloy included~~contained~~ in the electrode, the protective metal film being disposed~~lying~~ on the electrode,~~;~~ a first insulating layer disposed~~lying~~ in a region other than a region where the at least one electrode is disposed~~lies~~, the thickness of the first insulating layer being substantially~~almost~~ equal to the total thickness of the electrode and the protective metal film,~~;~~ and a second insulating layer covering the protective metal film and the first insulating layer.

[0017] In ~~According to a specific aspect of~~ the second

preferred embodiment~~invention~~, an average density of an entire laminated structure including the electrode and the protective metal film is preferably at least about ~~more than~~ 1.5 times greater~~higher~~ than the density of the first insulating layer.

[0018] In ~~According to a specific aspect of~~ the first and second preferred embodiments~~inventions~~, the first and second insulating layers are preferably made of SiO_2~~.~~

~~According to another specific aspect of the first and second inventions~~, reflection of surface acoustic waves is preferably used in the surface acoustic wave device,~~.~~

~~According to another specific aspect of the first~~ and ~~second inventions,~~ the height of a convex portion on a surface of the second insulating layer is preferably about 0.03λ or less when the wavelength of a surface acoustic wave is λ.

[0019] In ~~According to another specific aspect of~~ the surface acoustic wave device according to~~of~~ the first and second preferred embodiments~~inventions~~, the height of a convex portion on the second insulating layer is preferably about 1/2 or less of the thickness of the electrode.

[0020] More preferably, the height of the convex portion is about 1/3 or less of the thickness of the electrode.

In ~~According to another specific aspect of~~ the surface acoustic wave device according to~~of~~ the first and second preferred embodiments~~inventions~~, the electrode primarily includes~~mainly contains~~ a metal that is heavier than Al. Preferably

~~According to another specific aspect of the surface acoustic~~

~~wave device according to the first and second inventions~~, the electrode primarily includes~~mainly contains~~ a metal selected from a group consisting of Au, Pt, Cu, Ta, W, Ag, Ni, Mo, NiCr, Cr, and Ti. And more preferably ~~According to another specific aspect of the surface acoustic wave device of the present invention~~, the electrode is made of Au or Pt and the thickness thereof is in the range of about 0.0017λ to about 0.06λ when the wavelength of a surface acoustic wave is λ.

[0021] According to another preferred embodiment~~specific aspect of the surface acoustic wave device~~ of the present invention, the electrode primarily includes~~mainly contains~~ a metal selected from a group consisting of Au, Ag, Ni, Mo, Zn, Cu, Pt, Ta, W, Cr, and Ti, and the thickness of the electrode is in the range shown in the following Table 1 when the wavelength of a surface acoustic wave is λ.

~~[~~Table 1~~]~~

Au	0.0017λ ～ 0.06λ
Pt	0.0017λ ～ 0.06λ
Ag	0.0035λ ～ 0.10λ
Ta	0.0025λ ～ 0.064λ
W	0.0035λ ～ 0.06λ
Cu	0.0058λ ～ 0.11λ
Ni	0.012λ ～ 0.12λ
Cr	0.012λ ～ 0.12λ
Ti	0.012λ ～ 0.12λ
Mo	0.012λ ～ 0.12λ
Zn	0.012λ ～ 0.12λ

[0022] According to preferred embodiment~~another specific~~

~~aspect~~ of the surface acoustic wave device~~ of the present invention~~, the thickness of the second insulating layer is in the range of about 0.15λ to about 0.4λ when the wavelength of a surface acoustic wave is λ.

[0023] ~~—~~Preferably, the thickness of the ~~first~~second insulating layer is in the range of about 0.2λ to about 0.3λ when the wavelength of a surface acoustic wave is λ.

[0024] ~~—~~According to another preferred embodiment~~specific aspect~~ of the surface acoustic wave device~~ according to the present invention~~, Euler angles of the piezoelectric substrate made of $LiNbO_3$ are in the ranges shown in the following Table 2.

~~[~~Table 2~~]~~

Euler angles
(0±5, 62～167, 0±10)
(0±5, 87～158, 20±10)
(0±5, 112～165, 80±10)
(0±5, 107～167, 100±10)
(10±5, 110～162, 80±10)
(10±5, 69～108, 100±10)
(10±5, 72～140, 160±10)
(20±5, 99～121, 160±10)
(30±5, 67～113, 0±10)
(30±5, 27～125, 140±10)
(30±5, 67～103, 160±10)

[0025] According to another preferred embodiment~~specific aspect~~ of the surface acoustic wave device~~ according to the present invention~~, Euler angles of the piezoelectric substrate made of $LiNbO_3$ are in the ranges shown in the following Table 3.

~~[~~Table 3~~]~~

$k_R^2 \leq 0.01$
(0±5, 80～160, 0±10)
(0±5, 100～142, 0±10)
(0±5, 112～165, 80±10)
(0±5, 107～167, 100±10)
(10±5, 123～158, 80±10)
(10±5, 74～90, 100±10)
(10±5, 87～128, 160±10)
(20±5, 99～119, 160±10)
(30±5, 82～98, 0±10)
(30±5, 28～53, 140±10)
(30±5, 70～103, 160±10)

[0026] According to another preferred embodiment~~specific aspect~~ of the surface acoustic wave device~~ according to the present invention~~, Euler angles of the piezoelectric substrate

made of $LiNbO_3$ are in the ranges shown in the following Table 4.

~~[~~Table 4~~]~~

$k_R^2 \leq 0.049$
(0±5, 88～117, 0±10)
(0±5, 115～124, 0±10)
(0±5, 115～135, 80±10)
(0±5, 109～157, 100±10)
(10±5, 130～146, 80±10)
(10±5, 80～87, 100±10)
(10±5, 98～118, 160±10)
(20±5, 110～118, 160±10)
(30±5, 86～94, 0±10)
(30±5, 33～47, 140±10)
(30±5, 77～103, 160±10)

[0027] According to another preferred embodiment~~specific aspect~~ of the surface acoustic wave device~~ according to the present invention~~, Euler angles of the piezoelectric substrate made of $LiNbO_3$ are in the ranges shown in the following Table 5.

~~[~~Table 5~~]~~

Euler angles
(0±5, 38±10, 0)
(0±5, 89±10, 77～102±5)
(0±5, 130±10, 79±5)
(10±5, 110±10, 50～80±5)
(10±5, 110±10, 106±5)
(20±5, 100±10, 35～72±5)
(20±5, 100±10, 100～110±5)
(30±5, 89±10, 40～80±5)
(30±5, 100±10, 40～117±5)

[0028] According to still another preferred embodiment~~specific aspect~~ of the surface acoustic wave device ~~according to the present invention~~, Euler angles of the

piezoelectric substrate made of $LiNbO_3$ are in the ranges shown in the following Table 6.

~~[~~Table 6~~]~~

Euler angles
(0±5, 38±10, 0)
(0±5, 89±10, 80~100±5)
(10±5, 110±10, 50~80±5)
(20±5, 100±10, 42~70±5)
(30±5, 89±10, 42~76±5)
(30±5, 100±10, 42~72±5)

[0029] The surface acoustic wave device according to the first preferred embodiment~~invention~~ includes a first insulating layer disposed~~lying~~ in a region other than a region where at least one electrode is disposed~~lies~~, the thickness of the first insulating layer being substantially~~almost~~ equal to that of the electrode,~~;~~ and a second insulating layer covering the electrode and the first insulating layer. The ~~In this structure, the~~ electrode is made of a metal having a higher density than that of the first insulating layer or an alloy primarily including~~mainly containing~~ the metal, such~~so~~ that the electrode has a sufficient reflection coefficient. Accordingly, a SAW device which suppresses~~capable of suppressing~~ degradation of characteristics due to undesirable ripple and which has ~~having~~ a favorable temperature coefficient of frequency is ~~can be~~ provided.

[0030] In addition, the thickness of the IDT electrode is substantially~~almost~~ equal to that of the second ~~first~~ insulting layer, and the second insulating layer is laminated to cover the IDT and the first insulating layer. With this configuration, the

outer surface of the second insulating layer can be smoothed, such~~so~~ that degradation of characteristics due to unevenness of the surface of the second insulating layer is ~~can be~~ suppressed.

[0031] In the first preferred embodiment~~invention~~, the piezoelectric substrate is made of $LiNbO_3$ having an electromechanical coupling coefficient whose square is at least about ~~of~~ 0.025~~ or more~~. Thus, the bandwidth can be widened.

[0032] In the surface acoustic wave device according to the second preferred embodiment~~invention~~, the first insulating layer is disposed~~lies~~ in a region other than a region where the electrode is disposed~~lies~~ on the piezoelectric substrate made of $LiNbO_3$, the thickness of the first insulating layer is substantially~~being almost~~ equal to that of the electrode, the protective metal film is made of a metal or alloy that is more corrosion-resistant than a metal or alloy included~~contained~~ in the electrode~~ lies on the electrode~~, and the second insulating layer covers the protective metal film and the first insulating layer. Since the electrode is covered by the protective metal film and the first insulating layer, corrosion of the electrode due to a resist removing agent is~~can be~~ prevented when a resist is removed by photolithography. Therefore, the electrode can be made of a metal or alloy that is susceptible~~easy~~ to corrosion~~be corroded~~ by a resist removing agent,~~ or the like~~ but that has a sufficiently higher density than that of Al, for example, Cu. Accordingly, degradation of characteristics of the SAW device is~~can be~~ effectively suppressed.

[0033] In the second preferred embodiment~~invention~~, when an average density of an entire laminated structure including the electrode and the protective metal film is at least about ~~more than~~ 1.5 times greater~~higher~~ than the density of the first insulating layer, the reflection coefficient of the electrode is~~can be~~ effectively increased.

[0034] In the first and second preferred embodiments~~inventions~~, when the first and second insulating layers are made of SiO_2, a SAW device having an improved temperature coefficient of frequency TCF is~~can be~~ provided ~~according to the present invention~~.

[0035] In preferred embodiments of the present invention, when the height of the convex portion on the surface of the second insulating layer is about 0.03λ or less, ~~occurrence of~~ insertion loss is effectively~~can be~~ suppressed.

[0036] When the height of the convex portion on the second insulating layer is about 1/2 or less of the thickness of the electrode, insertion loss of the SAW device is~~can be~~ effectively suppressed. When the height of the convex portion is about 1/3 or less of the thickness of the electrode, the insertion loss is~~can be~~ suppressed more effectively.

[0037] Other features, elements, steps, characteristics and advantages of the present invention will become more apparent from the following detailed description of preferred embodiments of the present invention with reference to the attached drawings.

~~Brief Description of the Drawings~~ BRIEF DESCRIPTION OF THE DRAWINGS

[0038] Figs. 1A ~~Fig. 1(a)~~ to 1G ~~(g)~~ are schematic partially-cutout cross-sectional views illustrating a method for manufacturing a SAW device according to a preferred ~~an~~ embodiment of the present invention.

[0039] Fig. 2 is a schematic plan view of a one-port SAW resonator obtained in a preferred ~~an~~ embodiment of the present invention.

[0040] Fig. 3 shows a relationship between a thickness H/λ of a SiO_2 film and a temperature coefficient TCF when the SiO_2 film lies on a 13°, 30°, or 70°-rotated Y-cut X-propagating $LiNbO_3$ substrate.

[0041] Fig. 4 shows a relationship between a normalized thickness H/λ of a SiO_2 film and an electromechanical coupling coefficient k^2 in a structure where an interdigital electrode and the SiO_2 film lie on a 13°-rotated Y-cut X-propagating $LiNbO_3$ substrate.

[0042] Fig. 5 shows a relationship between θ of Euler angles (ϕ, θ, ψ) of a $LiNbO_3$ substrate and electromechanical coupling coefficients of a Rayleigh wave and a LSAW.

[0043] Fig. 6 shows a relationship between θ of Euler angles (ϕ, θ, ψ) of a $LiNbO_3$ substrate and electromechanical coupling coefficients of a Rayleigh wave and a LSAW.

[0044] Fig. 7 shows a relationship between θ of Euler angles (ϕ, θ, ψ) of a $LiNbO_3$ substrate and electromechanical

coupling coefficients of a Rayleigh wave and a LSAW.

[0045] Fig. 8 shows a relationship between θ of Euler angles (ϕ, θ, ψ) of a $LiNbO_3$ substrate and electromechanical coupling coefficients of a Rayleigh wave and a LSAW.

[0046] Fig. 9 shows a relationship between θ of Euler angles (ϕ, θ, ψ) of a $LiNbO_3$ substrate and electromechanical coupling coefficients of a Rayleigh wave and a LSAW.

[0047] Fig. 10 shows a relationship between θ of Euler angles (ϕ, θ, ψ) of a $LiNbO_3$ substrate and electromechanical coupling coefficients of a Rayleigh wave and a LSAW.

[0048] Fig. 11 shows a relationship between θ of Euler angles (ϕ, θ, ψ) of a $LiNbO_3$ substrate and electromechanical coupling coefficients of a Rayleigh wave and a LSAW.

[0049] Fig. 12 shows a relationship between θ of Euler angles (ϕ, θ, ψ) of a $LiNbO_3$ substrate and electromechanical coupling coefficients of a Rayleigh wave and a LSAW.

[0050] Fig. 13 shows a relationship between θ of Euler angles (ϕ, θ, ψ) of a $LiNbO_3$ substrate and electromechanical coupling coefficients of a Rayleigh wave and a LSAW.

[0051] Fig. 14 shows a relationship between θ of Euler angles (ϕ, θ, ψ) of a $LiNbO_3$ substrate and electromechanical coupling coefficients of a Rayleigh wave and a LSAW.

[0052] Fig. 15 shows a relationship between θ of Euler angles (ϕ, θ, ψ) of a $LiNbO_3$ substrate and electromechanical coupling coefficients of a Rayleigh wave and a LSAW.

[0053] Fig. 16 shows a relationship between θ of Euler

angles (ϕ, θ, ψ) of a $LiNbO_3$ substrate and electromechanical coupling coefficients of a Rayleigh wave and a LSAW.

[0054] Fig. 17 shows a relationship between θ of Euler angles (ϕ, θ, ψ) of a $LiNbO_3$ substrate and electromechanical coupling coefficients of a Rayleigh wave and a LSAW.

[0055] Fig. 18 shows a relationship between θ of Euler angles (ϕ, θ, ψ) of a $LiNbO_3$ substrate and electromechanical coupling coefficients of a Rayleigh wave and a LSAW.

[0056] Fig. 19 shows a relationship between θ of Euler angles (ϕ, θ, ψ) of a $LiNbO_3$ substrate and electromechanical coupling coefficients of a Rayleigh wave and a LSAW.

[0057] Fig. 20 shows a relationship between θ of Euler angles (ϕ, θ, ψ) of a $LiNbO_3$ substrate and electromechanical coupling coefficients of a Rayleigh wave and a LSAW.

[0058] Fig. 21 shows a relationship between θ of Euler angles (ϕ, θ, ψ) of a $LiNbO_3$ substrate and electromechanical coupling coefficients of a Rayleigh wave and a LSAW.

[0059] Fig. 22 shows a relationship between θ of Euler angles (ϕ, θ, ψ) of a $LiNbO_3$ substrate and electromechanical coupling coefficients of a Rayleigh wave and a LSAW.

[0060] Fig. 23 shows a relationship between a thickness of an electrode and an electromechanical coupling coefficient k^2 in electrodes made of different metals lying on a 13°-rotated Y-cut X-propagating $LiNbO_3$ substrate.

[0061] Fig. 24 shows a relationship between a thickness of an electrode and an attenuation constant α in electrodes made

of different metals lying on a 13°-rotated Y-cut X-propagating $LiNbO_3$ substrate.

[0062] Fig. 25 shows a relationship between a height of a convex portion on a surface of a SiO_2 film and insertion loss.

[0063] Fig. 26 shows a relationship between a ratio of a height of a convex portion on a surface of a SiO_2 film to a thickness of an interdigital electrode and insertion loss.

[0064] Fig. 27A~~(a)~~ and 27B~~(b)~~ are schematic plan views illustrating a one-port resonator and a two-port resonator as examples of a SAW device to which the present invention is applied.

[0065] Fig. 28 is a schematic plan view illustrating a ladder filter as a SAW device to which the present invention is applied.

[0066] Fig. 29 is a schematic plan view illustrating a lattice filter as a SAW device to which the present invention is applied.

[0067] Figs. 30A~~ Fig. 30(a)~~ to 30D~~(d)~~ are schematic cross-sectional views showing an example of a method for manufacturing a known SAW device.

[0068] Fig. 31 is a schematic front cross-sectional view illustrating an example of a known SAW device.

[0069] Fig. 32 shows a relationship between the thickness of an electrode and a reflection coefficient when the thickness of a SiO_2 film is 0.3λ in a structure including the SiO_2 film having a smooth surface, the electrode, and a 13°-rotated Y-cut

X-propagating $LiNbO_3$ substrate.

[0070] Fig. 33A~~(a)~~ to 33E~~(e)~~ show changes in impedance characteristic in accordance with change in ratio of an average density of an IDT electrode and a protective metal film to the density of a first insulating layer.

[0071] Fig. 34 shows a relationship between the thickness of an electrode and a reflection coefficient in a SAW device including a SiO_2 film having a thickness of about 0.2λ and a smooth upper surface placed on an electrode made of different metals placed on a $LiNbO_3$ substrate according to a preferred ~~an~~ embodiment of the present invention.

[0072] Fig. 35 shows a relationship between the thickness of an electrode and a reflection coefficient in a SAW device including a SiO_2 film having a thickness of about 0.25λ and a smooth upper surface placed on an electrode made of different metals placed on a $LiNbO_3$ substrate according to a preferred ~~the~~ embodiment of the present invention.

[0073] Fig. 36 shows a relationship between the thickness of an electrode and a reflection coefficient in a SAW device including a SiO_2 film having a thickness of about 0.3λ and a smooth upper surface placed on an electrode made of different metals placed on a $LiNbO_3$ substrate according to a preferred~~the~~ embodiment of the present invention.

[0074] Fig. 37 shows a relationship between the thickness of an electrode and a reflection coefficient in a SAW device including a SiO_2 film having a thickness of about 0.35λ and a

smooth upper surface placed on an electrode made of different metals placed on a $LiNbO_3$ substrate according to a preferred ~~the~~ embodiment of the present invention.

[0075] Fig. 38 shows a relationship between the thickness of an electrode and a reflection coefficient in a SAW device including a SiO_2 film having a thickness of about 0.4λ and a smooth upper surface placed on an electrode made of different metals placed on a $LiNbO_3$ substrate according to a preferred ~~the~~ embodiment of the present invention.

[0076] Fig. 39 shows a relationship between the thickness of an electrode and a reflection coefficient in a SAW device including a SiO_2 film having a thickness of about 0.5λ and a smooth upper surface placed on an electrode made of different metals placed on a $LiNbO_3$ substrate according to a preferred ~~the~~ embodiment of the present invention.

[0077] Fig. 40 shows a relationship between the thickness of an electrode and a reflection coefficient in a known SAW device including a SiO_2 film covering an IDT electrode and having an uneven surface, in which a $LiNbO_3$ substrate has Euler angles of (0°, 37.86°, 0°) and the thickness and material of the electrode is variously changed.

[0078] Fig. 41 shows a relationship between ψ in a $LiNbO_3$ substrate having Euler angles of (0°, 89°, ψ) and electromechanical coupling coefficients of a Rayleigh wave and a LSAW.

[0079] Fig. 42 shows a relationship between ψ in a $LiNbO_3$

substrate having Euler angles of (30°, 89°, ψ) and electromechanical coupling coefficients of a Rayleigh wave and a LSAW.

[0080] ~~___~~Fig. 43 shows a relationship between ψ in a $LiNbO_3$ substrate having Euler angles of (20°, 100°, ψ) and electromechanical coupling coefficients of a Rayleigh wave and a LSAW.

[0081] ~~___~~Fig. 44 shows a relationship between ψ in a $LiNbO_3$ substrate having Euler angles of (30°, 100°, ψ) and electromechanical coupling coefficients of a Rayleigh wave and a LSAW.

[0082] ~~___~~Fig. 45 shows a relationship between ψ in a $LiNbO_3$ substrate having Euler angles of (10°, 110°, ψ) and electromechanical coupling coefficients of a Rayleigh wave and a LSAW.

[0083] ~~___~~Fig. 46 shows a relationship between ψ in a $LiNbO_3$ substrate having Euler angles of (0°, 130°, ψ) and electromechanical coupling coefficients of a Rayleigh wave and a LSAW.

DETAILED DESCRIPTION OF PREFERRED EMBODIMENTS~~Reference Numerals~~

~~1 LiNbO3 substrate~~

~~2 first insulating layer~~

~~3 resist pattern~~

~~4 metal film~~

~~4A IDT electrode~~

~~5 Ti film as protective metal film~~

~~6 second insulating layer~~

~~11 SAW resonator~~

~~12 and 13 reflector~~

~~21 SAW device~~

~~22 $LiNbO_3$ substrate~~

~~23a and 23b IDT~~

~~25 SiO_2 film~~

~~Best Mode for Carrying Out the Invention~~

[0084] Hereinafter, ~~a~~ specific preferred embodiments~~embodiment~~ of the present invention are~~is~~ described with reference to the drawings.

[0085] A method for manufacturing a surface acoustic wave (SAW) device according to a first preferred embodiment of the present invention is described with reference to Figs. 1 and 2.

[0086] First, as shown in Fig. 1A~~(a)~~, a $LiNbO_3$ substrate 1 is prepared as a piezoelectric substrate.

[0087] A first insulating layer 2 is formed on an entire surface of the $LiNbO_3$ substrate 1. In this preferred embodiment, the first insulating layer 2 is made of a SiO_2 film.

[0088] The first insulating layer 2 is formed by an appropriate method, such as printing, evaporation, or sputtering. The thickness of the first insulating layer 2 is equal to that of an interdigital (IDT) electrode, which is formed later.

[0089] Then, as shown in Fig. 1B~~(b)~~, a resist pattern 3

is formed ~~by~~ using photolithography. The resist pattern 3 is formed such~~so~~ that a resist is disposed ~~placed~~ in a region except the region where the IDT electrode is to be formed.

[0090] Then, the first insulating layer 2, except a portion under the resist 3, is removed by reactive ion etching (RIE) or other suitable method~~the like~~ of applying ion beams, as indicated by arrows in Fig. 1C~~(c)~~.

[0091] If a SiO_2 film is etched by a reactive ion etching (RIE) device using a fluorine gas, a residue may be left by a polymerization reaction. In that case, the residue of the RIE may~~can~~ be treated with BHF (buffered hydrofluoric acid).

[0092] Subsequently~~ After that~~, a Cu film and a Ti film are formed such that the total thickness thereof is equal to that of the first insulating layer 2. As shown in Fig. 1D~~(d)~~, a Cu film 4 is formed in a region where the first insulating layer 2 has been removed, that is, in a region where an IDT is to be formed. At the same time, the Cu film 4 is formed on the resist pattern 3. Then, a Ti film 5 serving as a protective metal film is formed to cover the entire surface~~ is formed~~. As shown in Fig. 1E~~(e)~~, the Ti film 5 is formed on the upper surface of an IDT electrode 4A and on the Cu film 4 on the resist pattern 3. Accordingly, the IDT electrode 4A is covered by the first insulating layer 2 on its side surfaces and by the Ti film 5 on it upper surface. In this manner, the IDT electrode 4A and the protective metal film are formed, such that the total thickness of the IDT electrode 4A and the Ti film 5 serving as a protective metal film is the same

as the thickness of the first insulating layer 2.

[0093] The ~~After that, the~~ resist pattern 3 is then removed ~~by~~ using a resist removing agent. Accordingly, the structure shown in Fig. 1F is ~~1(f) can be~~ obtained. That is, the IDT electrode 4A is disposed~~lies~~ in a region where the first insulating layer 2 has been removed, and the upper surface of the IDT electrode 4A is covered by the Ti film 5.

[0094] Then, as shown in Fig. 1G~~(g)~~, a SiO_2 film as a second insulating layer 6 is formed over the entire surface.

[0095] Accordingly, a one-port SAW resonator 11 shown in Fig. 2 is produced~~obtained~~.

[0096] Figs. 1A ~~Fig. 1(a)~~ to 1G~~(g)~~ show only a portion~~part~~ where the IDT electrode 4A is formed. However, as shown in Fig. 2, the SAW resonator 11 includes reflectors 12 and 13, which are placed on both sides of the IDT electrode 4A in a SAW propagating direction. The reflectors 12 and 13 are formed by ~~through~~ the same process as that for the IDT electrode 4A.

[0097] In the above-described preferred embodiment, the one-port SAW resonator 11 is used, and thus, one IDT electrode 4A is provided on the $LiNbO_3$ substrate 1. However, a plurality of IDT electrodes may be provided depending on the ~~according to an~~ application of the SAW device. Further, the reflectors may be formed by~~through~~ the same process as that for the IDT as described above. Alternatively, the reflectors may not be provided.

[0098] The density of the IDT electrode 4A is at least

about ~~more than~~ 1.5 times greater ~~higher~~ than that of the first insulating layer 2, such~~so~~ that the IDT electrode 4A has a sufficient reflection coefficient.

[0099] SAW resonators were manufactured using~~in~~ the same method as that in the above-described preferred embodiment while variously changing the density of a metal contained in the IDT electrode 4A. The impedance characteristics of the respective SAW resonators obtained accordingly are shown in Figs. 33A to 33E. Figs. 33A~~. 33(a) to (c). Fig. 33(a)~~ to 33E~~(c)~~ show results obtained when the ratio ρ_1/ρ_2 of an average density ρ_1 of a laminated structure of the IDT electrode and the protective metal film to a density ρ_2 of the first insulating layer is approximately 2.5, 2.0, 1.5, 1.2, and 1.0, respectively.

[0100] As is clear from Figs. 33A~~. 33(a)~~ to 33E~~(c)~~, the above-mentioned ripple A is shifted outside the band in Figs. 33A~~. 33(a)~~ to 33C.~~(c).~~ Particularly, the ripple A is significantly suppressed in Fig. 33A~~(a)~~.

[0101] As can be understood from the results shown in Figs. 33A to 33E~~. 33~~, when the density of the laminated structure including the IDT electrode and the protective metal film is at least about ~~more than~~ 1.5 times greater~~higher~~ than that of the first insulating layer, the ripple A are ~~can be~~ shifted outside the band between a resonance frequency and an antiresonance frequency, and thus, a favorable characteristic is~~can be~~ obtained. More preferably, the ripple can be minimized when the density ratio is at least about 2.5:1~~ or more~~.

[0102] In Figs. 33A~~. 33(a)~~ to 33E~~(c)~~, the above-mentioned average density is used according to the above-described preferred embodiment because the Ti film is disposed~~lies~~ on the IDT electrode 4A. In the present invention, however, the protective metal film need not always be provided on the IDT electrode 4A. In that case, the thickness of the IDT electrode 4A should be the same as that of the first insulating layer, and the density of the IDT electrode should be at least about 1~~more than 1~~.5 times (more preferably, more than 2.5 times) greater~~higher~~ than that of the first insulating layer. It has been verified that the same advantages as those described above can be obtained with this structure.

[0103] Therefore, in the SAW resonator including the IDT electrode covered by the SiO_2 film, if the density of the IDT electrode or the average density of the laminated structure including the IDT electrode and the protective metal film is greater~~higher~~ than the density of the first insulating layer that is disposed~~placed~~ on side surfaces of the IDT electrode, the reflection coefficient of the IDT electrode is ~~can be~~ increased, and thus, degradation in characteristics~~characteristic emerging~~ between a resonance point and an antiresonance point is ~~can be~~ suppressed.

[0104] As a metal or an alloy having a higher density than that of Al, Ag, Au, or an alloy primarily including~~mainly containing~~ Ag or Au can be used as well as Cu.

[0105] Preferably, if the protective metal film is

laminated on the IDT electrode as in the above-described preferred embodiment, corrosion of the IDT electrode 4A is~~can be~~ prevented when the resist pattern 3 is removed because the side surfaces of the IDT electrode 4A are covered by the first insulating layer 2 and the upper surface thereof is covered by the protective metal film 5~~6~~, as is clear from the manufacturing method shown in Figs. 1A~~. 1(a)~~ to 1G.~~(g).~~ Accordingly, a SAW resonator having ~~a~~ more favorable characteristics is~~characteristic can be~~ provided.

[0106] Alternatively, the first and second insulating layers may be formed by using an insulating material having a temperature characteristic improving effect other than SiO_2, such as SiO_xN_y. The first and second insulating layers may be made of either different insulating materials or the same material.

[0107] In the above-described preferred embodiment, the $LiNbO_3$ ~~substrate 1 serving as a~~ piezoelectric substrate 1 is ~~should~~ preferably ~~be~~ a $LiNbO_3$ substrate having an electromechanical coupling coefficient k of a SAW whose square is at least about 0.025~~ or more~~. Accordingly, a SAW device having ~~of~~ a wide bandwidth is~~can be~~ provided.

[0108] The inventors of the present application examined a relationship between Euler angles and an electromechanical coupling coefficient by variously changing Euler angles of a $LiNbO_3$ substrate.

[0109] The temperature coefficient of frequency (TCF) of $LiNbO_3$ is negative: -80 to -110 ppm/°C, which is not very~~so~~

favorable. For improvement, a method for improving a TCF in a SAW device by forming a SiO_2 film having a positive TCF on a $LiNbO_3$ substrate is~~has been~~ known.

[0110] As shown in Fig. 3, if a SiO_2 film is formed on a 13°-rotated Y-cut X-propagating (Euler angles of (0°, 103°, 0°)) $LiNbO_3$ substrate, an optimum thickness of the SiO_2 film is about 0.27λ where~~when~~ the wavelength is λ. That is, the TCF is 0 (zero) when the thickness of the SiO_2 film is about 0.27λ. The optimum thickness of the SiO_2 film varies as ~~if~~ the azimuth angle of the $LiNbO_3$ substrate changes. However, as is clear from Fig. 3~~1~~, a temperature coefficient TCF of almost 0 (zero) is~~can be~~ obtained when the thickness of the SiO_2 film is in the range of about 0.18λ to about 0.34λ to the wavelength.

[0111] On the other hand, Fig. 4 shows a relationship between a normalized thickness H/λ of a SiO_2 film and an electromechanical coupling coefficient k^2 in a structure where an IDT electrode and a SiO_2 film are disposed~~lie~~ on a 13°-rotated Y-cut X-propagating $LiNbO_3$ substrate. Fig. 4 shows results obtained in respective IDT electrodes of a about 0.005λ to about 0.01λ thickness made of various metallic materials.

[0112] As shown in~~is clear from~~ Fig. 4, the electromechanical coupling coefficient k^2 is decreases~~lower~~ as the thickness H/λ of the SiO_2 film increases.~~is larger.~~ Thus, the SiO_2 film should be as thin as possible.

[0113] As described above, and as shown in~~is clear from~~ Figs. 3 and 4, the thickness of the SiO_2 film is preferably~~should~~

~~desirably be~~ in the range of about 0.2λ to about 0.35λ, when both the temperature coefficient of frequency TCF and the electromechanical coupling coefficient k^2 are considered~~taken into consideration~~.

[0114] Where ~~Under the condition where~~ the thickness of the SiO_2 film is about 0.3λ, a relationship between θ of Euler angles and an electromechanical coupling coefficient of a Rayleigh wave was examined in $LiNbO_3$ substrates of different Euler angles. The results are shown in Figs. 5 to 22.

[0115] It is ~~generally~~ known that a leaky surface acoustic wave (LSAW) is difficult to generate~~hardly generated~~ when θ of Euler angles (0, θ, 0) is in the range of about 20° to about 40°. When a thin SiO_2 film is disposed~~lies~~ on the upper surface of an IDT electrode~~ or the like~~, a LSAW portion of a low electromechanical coupling coefficient ranges from about ~~around~~ 20° to about 40° of θ of Euler angles (0, θ, 0), as indicated with the dotted line shown in Fig. 5.

[0116] In general, an electromechanical coupling coefficient k^2 required in a RF filter or a duplexer is at least about 0.025~~ or more~~. In addition, if a LSAW is used, the spurious of a Rayleigh wave must~~needs to~~ be small. That is, when the electromechanical coupling coefficient of a Rayleigh wave is k_R^2 and when the electromechanical coupling coefficient of a LSAW is k_{LSAW}^2, $(k_{LSAW}^2/4) \geq k_R^2$ must~~should~~ be satisfied.

[0117] Table 7 shows the ranges of Euler angles that~~to~~ satisfy such a range. Since $LiNbO_3$ is a crystal of trigonal

system, Euler angles have the following relationship:

$$(\phi, \theta, \psi) = (60+\phi, -\theta, \psi) = (60-\phi, -\theta, 180-\psi)$$
$$= (\phi, 180+\theta, 180-\psi) = (\phi, \theta, 180+\psi).$$

[0118] Thus, for example, Euler angles (10, 30, 10) are equivalent to Euler angles (70, -30, 10), (50, -30, 170), (10, 210, 170), and (10, 30, 190).

~~[~~Table 7~~]~~

Euler angles	LSAW		Rayleigh	
	k	k^2	k	k^2
(0±5, 62～167, 0±10)	0.22 ～ 0.43	0.0484 ～ 0.1849	0.02 ～ 0.17	0.0004 ～ 0.0289
(0±5, 87～158, 20±10)	0.24 ～ 0.32	0.0576 ～0.1024	0.07 ～ 0.16	0.0049 ～ 0.0256
(0±5, 112～165, 80±10)	0.16 ～ 0.22	0.0256 ～ 0.0484	0.01 ～ 0.10	0.0001 ～ 0.01
(0±5, 107～167, 100±10)	0.16 ～ 0.21	0.0256 ～ 0.0441	0.01 ～ 0.10	0.0001 ～ 0.01
(10±5, 110～162, 80±10)	0.17 ～ 0.39	0.0289 ～ 0.1521	0.05 ～ 0.17	0.0025 ～ 0.0289
(10±5, 69～108, 100±10)	0.27 ～ 0.37	0.0729 ～ 0.1369	0.07 ～ 0.18	0.0049 ～ 0.0324
(10±5, 72～140, 160±10)	0.24 ～ 0.32	0.0576 ～ 0.1024	0.06 ～ 0.15	0.0036 ～ 0.0225
(20±5, 99～121, 160±10)	0.16 ～ 0.20	0.0256 ～ 0.04	0.03 ～ 0.11	0.0009 ～ 0.0121
(30±5, 67～113, 0±10)	0.32 ～ 0.35	0.1024 ～ 0.1225	0.06 ～ 0.17	0.0036 ～ 0.0289
(30±5, 27～125, 140±10)	0.21 ～ 0.41	0.0441 ～ 0.1681	0.05 ～ 0.17	0.0025 ～ 0.0289
(30±5, 67～103, 160±10)	0.16 ～ 0.30	0.0256 ～ 0.09	0.03 ～ 0.10	0.0009 ～ 0.01

[0119] Preferably, the Euler angles should be in the ranges shown in Table 8. In this~~that~~ case, the electromechanical coupling coefficient k_R^2 of a Rayleigh wave is about 0.01 or less.

~~[~~Table 8~~]~~

$k_R^2 \leq 0.01$
(0±5, 80～160, 0±10)
(0±5, 100～142, 0±10)
(0±5, 112～165, 80±10)
(0±5, 107～167, 100±10)
(10±5, 123～158, 80±10)
(10±5, 74～90, 100±10)
(10±5, 87～128, 160±10)
(20±5, 99～119, 160±10)
(30±5, 82～98, 0±10)
(30±5, 28～53, 140±10)
(30±5, 70～103, 160±10)

[0120] More preferably, the Euler angles should be in the ranges shown in Table 9. In this~~that~~ case, k_R^2 is about 0.~~0~~049 or less.

~~[~~Table 9~~]~~

$k_R^2 \leq 0.049$
(0±5, 88～117, 0±10)
(0±5, 115～124, 0±10)
(0±5, 115～135, 80±10)
(0±5, 109～157, 100±10)
(10±5, 130～146, 80±10)
(10±5, 80～87, 100±10)
(10±5, 98～118, 160±10)
(20±5, 110～118, 160±10)
(30±5, 86～94, 0±10)
(30±5, 33～47, 140±10)
(30±5, 77～103, 160±10)

[0121] Fig. 23 shows electromechanical coupling coefficients k^2 in electrodes made of various metallic materials disposed~~lying~~ on a 13°-rotated Y-cut X-propagating $LiNbO_3$ substrate. As is clear from Fig. 23, the electromechanical coupling coefficient k^2 changes in accordance with changes in thickness of the electrode. It has been verified that the thickness of the electrode required to obtain a k^2 of about 1.25 times greater ~~higher~~ than k^2 when the electrode is not formed is in the range of about 0.0017 to about 0.03 to the wave length, if the electrode is made of Au. Although not shown in Fig. 23~~the figure~~, the range of thickness is the same in an electrode made of Pt. The range is about 0.0035 to about 0.05 in Ag, about 0.0025 to about 0.032 in Ta, about 0.0035 to about 0.03 in W, about 0.0058 to about 0.055 in Cu, about 0.125 to about 0.08 in Ni, about 0.033 to about 0.12 in Al, and about 0.012 to about 0.12 in Cr, Ti, Mo, or Zn.

[0122] The upper limit of the above-described range of the thickness of an electrode is limited by the accuracy of forming an interdigital electrode. That is, it is difficult to form an interdigital electrode having a ~~larger~~ thickness greater than the above-described thickness with high accuracy.

[0123] The optimum thickness of an electrode differs depending on the Euler angles of a $LiNbO_3$ substrate. However, the maximum of the optimum thickness is, at most, about twice ~~of~~ the minimum thickness~~at most~~.

[0124] Since the upper limit of the thickness of an electrode is about 0.12λ in Al, the optimum thickness of the electrode is about 0.0017λ to about 0.06λ in Au, about 0.0017λ to about 0.06λ in Pt, about 0.0035λ to about 0.10λ in Ag, about 0.0025λ to about 0.064λ in Ta, about 0.0035λ to about 0.06λ in W, about 0.0058λ to about 0.11λ in Cu, about 0.012λ to about 0.12λ in Ni, and about 0.033λ to about 0.12λ in Al.

[0125] Fig. 24 shows changes in propagation constant relative to the thickness of an electrode in SAW devices including electrodes of different materials with the above-described optimum thickness. As is clear from Fig. 24, the propagation loss is substantially ~~almost~~ 0 (zero) in these thicknesses.

[0126] When the first and second insulating layers are made of SiO_2, in other words, when a SiO_2 film is formed to cover an interdigital electrode, as shown in Figs. 1 and 2, a convex portion is generated on the upper surface of the SiO_2 film due to

the shape of the interdigital electrode. If the convex portion is large, that is, if the convex on the surface of the second insulating layer 6 is high, the characteristics of the SAW device degrade~~s~~. Fig. 25 shows changes in insertion loss according to changes in height of the convex portion on the surface of the SiO_2 film. As is clear from Fig. 25, the insertion loss is ~~can be~~ suppressed if the height of the convex portion is about 0.03λ or less~~, which is desirable~~.

[0127] The height of the convex portion on the surface of the SiO_2 film is a distance from the bottom to the top of the convex portion.

[0128] Fig. 26 shows changes in insertion loss when the ratio between the height of the convex portion on the surface of the SiO_2 film and the thickness of the interdigital electrode is varied. As~~changed. In the result~~ shown in Fig. 26, white circles indicate the case where the normalized film thickness H/λ of the IDT is about 0.06λ, black triangles indicate the case where the thickness is about 0.03λ, and crosses indicate the case where the thickness is about 0.08λ.

[0129] As is clear from Fig. 26, the height of the convex portion on the surface of the SiO_2 film is preferably no more than ~~should be~~ half ~~or less~~ of the thickness of the interdigital electrode and the height should be about 0.04λ or less. More preferably, the height of the convex portion should be about 1/3 or less of the thickness of the interdigital electrode and the height should be 0.03λ or less. More preferably, the surface of

the SiO_2 film is uniform and is not uneven~~hardly has unevenness~~.

[0130] ~~In~~ In a typical SAW device, an adequate stop band is not generated if the reflection coefficient is low. Therefore, a SAW device having a low reflection coefficient does not operate as a resonator. When a SAW device is used as a SAW resonator, the reflection coefficient of the SAW device must~~needs to~~ be at least about 0.03~~ or more~~. Thus, the thickness of the electrode must be set such~~so~~ that a reflection coefficient of at least about 0.03 is~~or more can be~~ obtained by considering a relationship between the reflection coefficient and the thickness of the electrode. Figs. 34 to 39 show a relationship between the reflection coefficient in a structure where the surface of the SiO_2 film is smoothed and the thickness of respective electrodes made of Au, Ag, Ta, Cu, W, and Al. Herein, a 127.86°-rotated Y-cut X-propagating $LiNbO_3$ substrate is used as a substrate. The Euler angles of this substrate are (0°, 37.86°, 0°).

[0131] As shown in~~is clear from~~ Figs. 34 to 39, even if the thickness of the SiO_2 film changes in the range of about 0.2λ to about 0.5λ, a reflection coefficient of at least about 0.03 is ~~or more can be~~ obtained when Au, Ag, Ta, Cu, or W (except Al) is used as a material of the electrode.

[0132] Incidentally, the range of the vicinity of the above-described Euler angles (0°, 37.86°, 0°) is the range of Euler angles in which the electromechanical coupling coefficient of a Rayleigh wave is high and the electromechanical coupling coefficient of a LSAW is low. In the range of ~~the vicinity of~~

these Euler angles, the reflection coefficient is substantially~~almost~~ 0 (zero). For this reason, substrates having those Euler angles have conventionally been used only in transversal filters, in which the reflection coefficient should be low. That is, this type of substrate cannot be used in devices requiring reflection of fingers as shown in Figs. 27 to 29. Furthermore, in a conventional structure having an uneven surface of a SiO_2 film, the reflection coefficient obtained is almost the same as that when Al is used, even if a heavy metal such as Cu or Ag is used for an IDT electrode. Fig. 40 shows a relationship between a reflection coefficient and the thickness of an electrode in a conventional structure with an uneven surface of a SiO_2 film.

[0133] Fig. 40 shows changes in reflection coefficient according to changes in thickness of an electrode in a conventional structure where an electrode made of different metallic materials is formed on the above-described $LiNbO_3$ substrate having Euler angles of (0°, 37.86°, 0°) and a SiO_2 film having a normalized thickness of about 0.4λ covers the electrode. As shown in~~is clear from~~ Fig. 40, when a $LiNbO_3$ substrate having the above-described Euler angles is used and when the electrode is made of a heavy metal such as Cu, the reflection coefficient obtained is as low as that when Al is used regardless of the thickness of the electrode.

[0134] A high electromechanical coupling coefficient of a Rayleigh wave and a low electromechanical coupling coefficient of

a LSAW are ~~can be~~ obtained in a plurality of ranges of Euler angles other than the above-described range. The following Tables 10 and 11 show those ranges of Euler angles. Also, Figs. 41 to 46 show the ranges of Euler angles.

[0135] More specifically, Figs. 41 to 46 show a relationship between ψ when ~~in the cases of using~~ $LiNbO_3$ substrates having Euler angles of (0°, 89°, ψ), (30°, 89°, ψ), (20°, 100°, ψ), (30°, 100°, ψ), (10°, 110°, ψ), and (0°, 130°, ψ), respectively, are used, and electromechanical coupling coefficients of a Rayleigh wave and a LSAW. As is clear from Figs. 41 to 46, when $LiNbO_3$ substrates of various Euler angles are used, the electromechanical coupling coefficient of a Rayleigh wave is high and the electromechanical coupling coefficient of a LSAW is low in a plurality of ranges of Euler angles.

[0136] Table 10 shows a plurality of ranges of Euler angles (ϕ, θ, ψ) of a $LiNbO_3$ substrate which ~~to~~ satisfy $K_{RAY}^2 \geq 0.05$ and $K_{LSAW}^2 \leq 0.02$. Table 11 shows a plurality of ranges of Euler angles (ϕ, θ, ψ) of a $LiNbO_3$ substrate which ~~to~~ satisfy $K_{RAY}^2 \geq 0.05$ and $K_{LSAW}^2 \leq 0.01$.

[0137] The same characteristics as those shown in Figs. 34 to 39 can be obtained in the ranges of Euler angles shown in Tables 10 and 11. In the ranges of Euler angles shown in Tables of this description, ±5 or ±10 is the tolerance of an angle calculated by considering a processing accuracy of Euler angles when the devices are mass-produced and a difference in specific

gravity of a material of an electrode having a small specific gravity, such as Cu, and a material of an electrode having a very great specific gravity, such as Au.

~~[~~Table 10~~]~~

φ	θ	ψ	k		k^2	
			RAY	LSAW	RAY	LSAW
0±5	38±10	0	0.29	0.10	0.0841	0.009
0±5	89±10	77～102±5	0.22～0.31	0.06～0.14	0.050～0.096	0.004～0.020
0±5	130±10	79±5	0.27	0.13	0.073	0.017
10±5	110±10	50～80±5	0.22～0.23	0.06～0.08	0.050～0.053	0.004～0.006
10±5	110±10	106±5	0.22	0.11	0.048	0.012
20±5	100±10	35～72±5	0.22～0.24	0.04～0.14	0.050～0.058	0.002～0.020
20±5	100±10	100～110±5	0.22～0.26	0.11～0.14	0.050～0.068	0.012～0.020
30±5	89±10	40～80±5	0.24～0.28	0.04～0.14	0.058～0.078	0.002～0.020
30±5	100±10	40～117±5	0.22～0.32	0.04～0.14	0.050～0.102	0.002～0.020

~~[~~Table 11~~]~~

φ	θ	ψ	k		k^2	
			RAY	LSAW	RAY	LSAW
0±5	38±10	0	0.29	0.10	0.084	0.009
0±5	89±10	80～100±5	0.23～0.25	0.06～0.10	0.053～0.063	0.004～0.010
10±5	110±10	50～80±5	0.22～0.23	0.06～0.08	0.050～0.053	0.004～0.006
20±5	100±10	42～70±5	0.22～0.23	0.04～0.10	0.050～0.053	0.002～0.010
30±5	89±10	42～76±5	0.24～0.28	0.04～0.10	0.058～0.078	0.002～0.010
30±5	100±10	42～72±5	0.22～0.24	0.04～0.10	0.050～0.058	0.002～0.010

[0138] Fig. 32 shows a relationship between a reflection coefficient of each electrode finger of an Al electrode, a W electrode, and a Cu electrode, respectively, and the thickness of the electrode. A SiO_2 film is provided~~exists~~ between electrode fingers and on the electrode fingers.

[0139] The thickness of the SiO_2 film on the substrate is about 0.3λ and the surface of the SiO_2 film is even. The substrate is made of 13°-rotated Y-cut X-propagating $LiNbO_3$. As is clear from Fig. 32~~the figure~~, Al electrode fingers have a low reflection coefficient, and the reflection coefficient does not increase, ~~become high~~ even if the film thickness increases. In contrast, electrode fingers made of heavy W or Cu have a higher reflection coefficient than that of Al. Further, the reflection

coefficient becomes higher as the film thickness is larger. As described above, an IDT including ~~composed of~~ electrode fingers having a~~of higher~~ density greater than that of Al has a high reflection coefficient, and thus is suitable for a resonator, a resonator filter, and a ladder filter.

[0140] The present invention can be applied to various SAW devices. Examples of those SAW devices are shown in Figs. 27A~~(a) and (b)~~ to 29. Fig. 27A~~(a)~~ and 27B~~(b)~~ are schematic plan views showing electrode structures of a one-port SAW resonator 47 and a two-port SAW resonator 48, respectively. A two-port SAW resonator filter may be configured by using the same electrode structure as that of the two-port SAW resonator 48 shown in Fig. 27B~~(b)~~.

[0141] Figs. 28 and 29 are schematic plan views showing electrode structures of a ladder filter and a lattice filter, respectively. By forming the electrode structure of the ladder filter 49a shown in Fig. 28 or the lattice filter 49b shown in Fig. 29 on a piezoelectric substrate, a ladder filter or a lattice filter can be configured according to preferred embodiments of the present invention.

[0142] The present invention can be applied to various SAW devices, in addition to the SAW devices having the electrode structures shown in Figs. 27 to 29.

[0143] While preferred embodiments of the present invention have been described above, it is to be understood that variations and modifications will be apparent to those skilled in the art

without departing the scope and spirit of the present invention. The scope of the present invention, therefore, is to be determined solely by the following claims.